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Managing Variability in Ocean Shipping

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Purpose: The paper aims to explore the relationship between time-related variables in global ocean transportation networks (GOTNs) and the shipper's inventory management performance. We modelled fill rates with daily and weekly sailings, and analysed the impact of variability on these on the shipper's inventory management system.

Design/ methodology/approach: We conducted simulation modelling of the above variables, and supplemented these by means of interviews with executives in a number of liner operators, 3PLs, freight forwarders and a large automotive shipper.

Findings: Improvements in variability have different impacts, depending on the source of the variability and the frequency of the shipments. The highest inventory reduction potential arises from a combination of high reliability and improved frequency.

Practical Implications: We have demonstrated the potential advantages of reduced variability and improved frequency of sailings. We have positioned port-to port (P2P) in the context of door-to-door (D2D) supply chain movements.

Originality and value: We have developed clear quantitative analyses of time-based factors in operating GOTNs

Keywords: global ocean transportation, variability of transit times, inventory management, simulation, supply chain performance

1. Introduction

Design and management of a global ocean transportation network (GOTN) spans multiple continents and involves a variety of business units. Such a network influences operations from procurement through to final assembly and thence into finished product distribution. With the increasing amount of global operations, outsourcing and off-shoring, ocean transport has become a critical part of most supply chains. As Fransoo and Lee (2011) put it 'containerised ocean transport has become the lifeline of almost any global supply chain'.

As GOTNs become more global in their reach, managing liner services has become an increasingly challenging endeavour. Shipping lines design the networks they find convenient to offer, but at the same time they are contracted to provide the services their customers want in terms of frequency, direct accessibility and transit times (Notteboom and Rodrigue, 2008). The challenge for liner operators often becomes one of supporting just-in-time assembly and retail operations, where speed and delivery reliability are key factors.

In practice, there appears to be little or no attention to end-to-end supply chain focus (Fransoo and Lee, 2011). Instead, shipping operations are more typically focused on utilizing scarce assets, and on cutting port fees and tariffs. The pressure is often to put more emphasis on port fees and tariffs than on costs related to service time and reliability, because 'it is easier to measure the impact of port fees and tariffs on the carrier's bottom line than the impact of service time and reliability' (Notteboom, 2006). From a supply chain perspective, the performance of the liner operators should be evaluated on the impact of their operations on the rest of the supply chain. But a move towards a service-oriented approach by some of the operators in the market place has taken place only comparatively recently.

Short transit times and high schedule reliability are key factors for shippers and have become important objectives of such operators (Notteboom, 2006). McKinnon (2012) found a similar result based on a survey on the importance of factors affecting the shipper's choice of deep-sea container services. Reliability was identified as the third most important topic after cost and the condition of goods on arrival, and has a higher importance than the frequency and speed of the service.

The penalty for a poor performance in the time factor is inventory. Long transit times translate into high pipeline inventories through Little's law (Little 1961), which states that inventory in a pipeline increases with transportation time if transportation speed remains the same. As a consequence of increased pipeline inventory, more capital is tied up in the business in order to satisfy the same level of demand (increased cash-to-cash cycle time). Poor reliability in transit times on the other hand must be buffered by safety stocks on the receiving side, for example in a central warehouse. The balance between service and freight rates was analysed by Leachman (2008) based on import volumes routed through North American West Coast ports. He concludes that "ports and carriers [which are] able to mitigate existing or potential congestion, and offer importers more reliable and shorter lead times, stand to gain larger shares of traffic – but only if the increases in transportation charges do not outweigh the economic value of the reduced lead times".

Economic value here is based on inventory related costs. This view particularly applies when the company which owns the goods (the shipper) has direct control over the transportation network. If the shipper contracts a third party to take care of container shipment (e.g. a freight forwarder), the immediate economic value considered by the third party contractor may not be directly related to inventory levels. Thus De Langen (2007) found that freight forwarders and shippers have different priorities in selecting ports. Freight forwarders were willing to accept lower service for lower prices, while shippers prioritised service because of potential costs to the supply chain which are not related to transportation costs. Similarly, Tongzon and Sawant (2007) found that although the shipping lines state that the most important criteria for their port selection is service in terms of efficiency, there is empirical evidence that their actual preferences are more to do with port charges and range of services.

The aim of this paper is to explore the impact of the time factor in GOTNs on supply chain performance of shippers with respect to their inventory management and end customer service levels. We specifically focus on the impact of the time factor on the shipper's inventory related cost. This analysis allows us to identify potentials and competitive factors for ocean carriers.

Section 2 presents the time factor and discusses relevant time-related elements: transit time, schedule and transit variability, and frequency. In Section 3 we build a simulation model to analyse the impact of the time factor on the shipper's inventory management. The simulation of such a two-stage supply chain model is based on the discussion of the time factor in Section 2 and empirical data gathered from interviews. .Our summary and conclusions are presented in Section 4.

Evidence for our paper was collected from interviews with executives from a global auto manufacturer, from a number of carriers (notably Maersk CMA-CGM and NYK line) as well as from interviews with the port operator Forth Ports, the shipping information provider Sea Intel Maritime Analysis, freight forwarder (Damco), and with logistics service providers like CEVA Logistics and Kühne and Nagel. We also collected data from academic sources, and industry reports from Drewry and Alphaliner.

2. Time factor

2.1. *Transit times*

Transit time has a number of definitions, for example the number of sailing days on a port-to-port (P2P) basis. In a wider sense, transit time is the total time (normally in days) on a door-to-door (D2D) basis. This by nature includes dwell time at relay points across the network, and time needed to move between each relay point on the network. The approach adopted in the literature and by the people we interviewed was that 'transit time', in the shipping environment, refers to the number of sailing days or ocean transit between ports (P2P).

While the focus in shipping is most often on P2P timings, customers are most interested in overall D2D statistics for both transit time and variability, as this includes any land-based movements to and from the port of entry. P2P times are a subset of overall D2D times, and directly relate to the amount of time that the ship is at sea and the number of port stops that occur between the customer's port of departure and arrival.

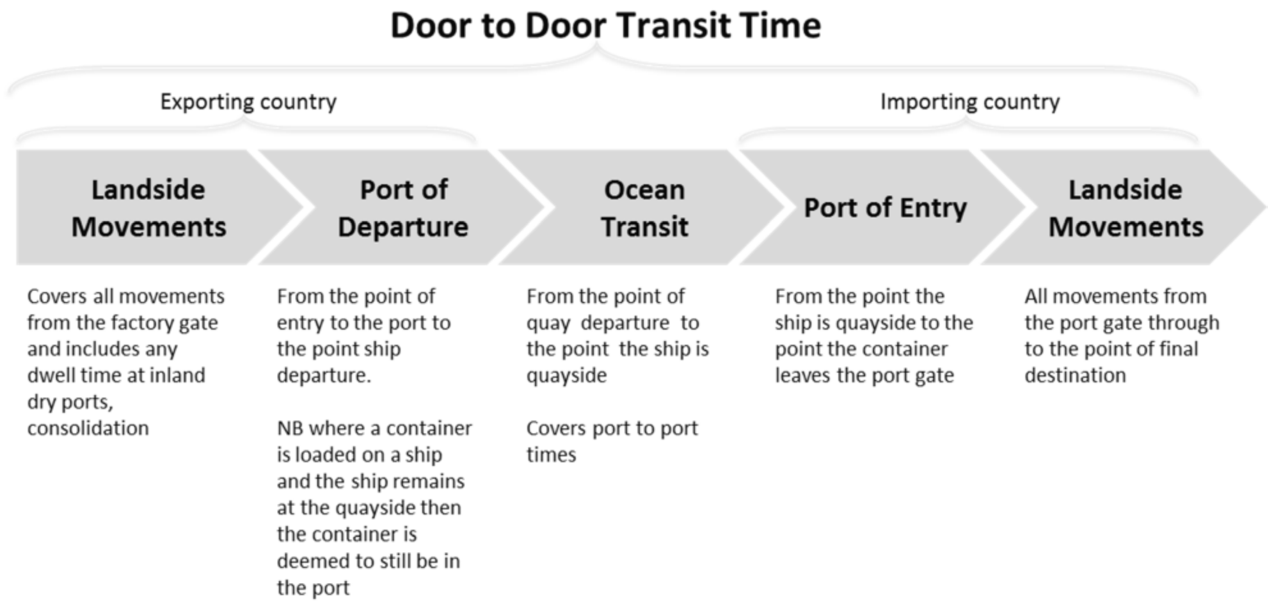

Figure 1: Transit characteristics

Transit time performance is a critical point when it comes to selecting ocean carriers. A short transit time is preferable unless it is accompanied by high P2P variability.

2.2. *Schedule variability and transit variability*

GOTNs are defined by time constrained schedules consisting of multiple journeys or strings. Each string takes a significant amount of time to develop; the ideal result being a combination of a number of ports located close together (short transit times) with a high degree of schedule reliability. The short transit times mean more boxes can be loaded and unloaded; and the schedule reliability, enables carriers maximize their time in port. The combination of the two enables customers to effectively plan their operations.

The driving factor in ocean freight is schedule variability, which is defined by Drewry (2010) as:

"the scheduled day of arrival at the destination port (announced by the carrier at least two weeks before the date of departure) and the actual day of arrival for the same ship at the destination port"

Simply put, this is the difference between the planned arrival date and the actual arrival date. Where variability does occur, it affects both carrier and customer. The carrier incurs costs in the form of additional operating costs, linked, for example, to unproductive vessel time and the rescheduling of vessels. The customer incurs logistics costs relative to holding additional inventory in the form of safety stock and pipeline stock and where the materials are part of a wider production process, additional production costs e.g. stoppages whilst the line waits for delayed materials.

In theory, slow steaming improves schedule reliability because vessels can adjust speed to make up time over the route. One way of maintaining schedule integrity is to effectively manage transit variability in conjunction with slow steaming e.g. should a vessel depart late from a port, they can increase speed during the ocean voyage to bring the schedule back into line again. This does require the carrier to be willing to increase speed, thus consuming more fuel in the process. Utilizing these two definitions, it is possible for liners to show significant ocean transit variability between port pairings, but very low overall schedule variability across the string.

But slow steaming creates adverse effects to client supply chains. Changes in schedules across the various operators increase congestion at ports, and at other bottlenecks such as the Suez Canal. We note that it is not slow steaming per-se causing these effects, but the change in schedules. In turn, this impacts schedule reliability and port turn-around times. Further problems for client supply chains result from the slower rates of material flow, which increases pipeline inventories and associated financing costs. The bullwhip effect amplifies these changes to flow rates.

The other key factor that can influence schedule variability is the number of ports visited on a string i.e. the more ports the greater chance of schedule variation, conversely on a string covering Asia-Europe , loading goods on at the last port in Asia and off-loading at the first port in Europe provides consistent schedule and transit performance.

Given the high degree of variability in transit times of ocean freight, 55% for the first quarter 2010 (Drewry, 2010), movement by sea is not viewed as an effective option for a JIT environment. Carriers and 3PL operators both advise that scheduled delivery times should be buffered by means of safety stocks. The exceptions to this are the carriers that are heavily focused on service.

The sequence of pick-up and delivery ports is also a major factor in determining transit variability (Vernimmen et al, 2007). For example, if a container is loaded at the last port of a departure string and unloaded at the first port in the arrival it is expected to have minimal variability since there are no interim ports. If, on the other hand, a container is loaded at the first port in the departure string and unloaded at the last port in the arrival string, it has a higher likelihood of being interrupted due to potential delays at the intervening four ports in the string.

The ideal arrangement for a customer needing to reduce schedule variability is to load goods on at the last port in the string relative to the originating location, and then to unload them at the first port relative to the destination. The inherent risk is that no space is left on the carrier to take the goods. To minimize this risk, customers need to be able to effectively forecast requirements and to make the corresponding cover bookings.

2.3. Sources of variability

Delay across the supply chain can be attributed to three areas of operation, the landside movements, the ocean movement (P2P), and port-based activities, which spans both landside and ocean side movements.

2.3.1. Sea based variability

An example of a Drewry (2010) schedule reliability report tracking the schedule reliability across the major shipping lines is shown in Table 1.

Table 1: Overall frequency of vessel arrivals by number of days early /late (adapted from Drewry schedule reliability insight for Q2, 2010)

Ship early (days)				Ship on time	Ship late (days)										Total arrivals
-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	
Overall frequency of vessel arrivals by number of days early /late															
7	19	31	126	812	346	163	95	71	28	26	31	24	9	4	1792
0%	1%	2%	7%	45%	19%	9%	5%	4%	2%	1%	2%	1%	1%	0%	

As stated above, the report showed a 55% on time arrival reliability in Q1 2010, increasing to 83% arrival at ETA + 2 days. This appears to be a relatively small variation in relation to the overall D2D timelines. This small level of variability has also been borne out in studies, which have found that ocean movement variability when compared to port movement variability is also relatively low. Notteboom (2006) found that ocean schedule variability or delay is attributed to four distinct groups: terminal operations, port access, maritime passages, and chance, with only terminal operations relating to landside activity. The other three groups all related to sea based operations across the string. As part of the study, Notteboom found that of the sources of delay across the group, the level of delays in the purely ocean part of the study were 6.2% (chance 5.3% and missed Suez convoy 0.9%). It is probable that the missed convoy may have been a direct result of delays in port at a point earlier in a string.

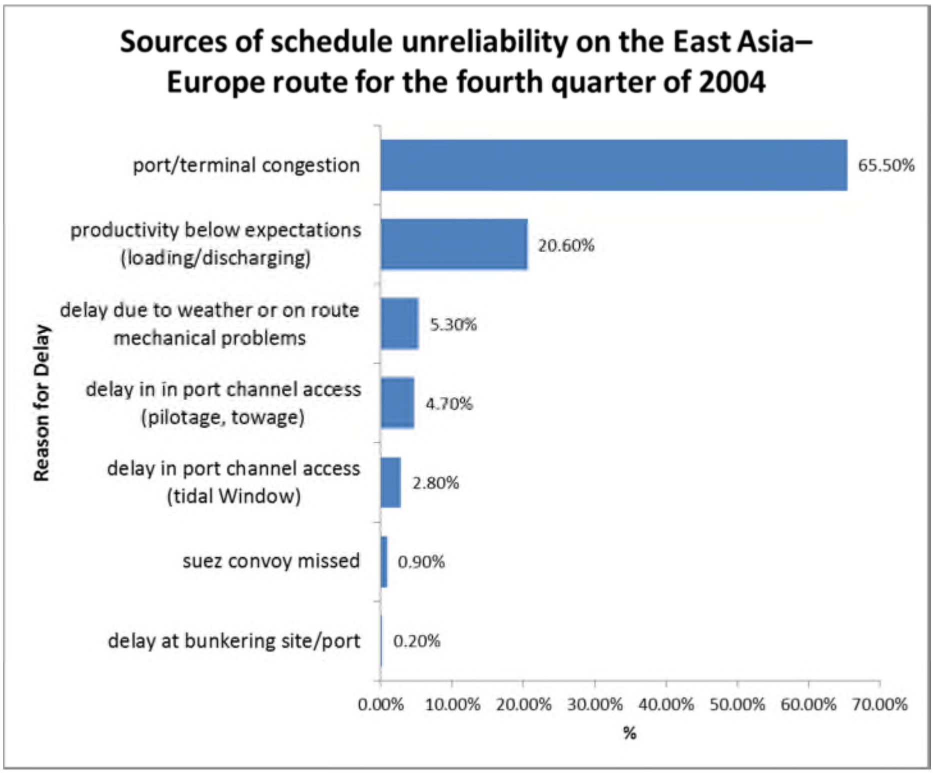

Figure 2 Sources of schedule unreliability on the East Asia-Europe route for the fourth quarter of 2004 (from Notteboom 2006: 24)

Our interview group responded that port productivity and congestion whilst waiting to access ports are still major factors today. However, congestion was probably less of an issue for some carriers because of the downturn in the market, increased levels of port ownership by carriers and greater use of berthing contracts. It should also be noted that congestion at ports is a direct result of the port infrastructure and/or the hinterland distribution network not being able to manage and handle the inflow of traffic, again leading to delay as a result of land based activities (Vernimmen et al, 2007). Thus both the studies and results from the interview panel indicate that actual P2P ocean transit times are not a major factor in schedule variability. Instead variability was driven by land and port based activities. Ironically, increasing the level of transit variability was seen as a way to help reduce the levels of schedule variability across the string.

As a result, customers trying to reduce variability within the overall D2D context need to focus on the land based activities that impact the overall variability in the travelling time. This includes the number of ports that a vessel stops at between the customer's pick-up port and delivery port, as each port potentially will add further land-based variation to the overall schedule timing.

2.3.2. Land based variability

As indicated previously, land based activities (including port processing time) form a key component of D2D movements. The intermodal nature of these movements has the potential to provide the greatest sources of variability across the supply chain network. Utilisation of intermodal transportation is heavily reliant on the effective synchronization of different freight movement systems and operators across a range of geographical scales. As the number of interfaces increases, the entire supply chain becomes more vulnerable to disruptions, leading to increased levels of schedule variability. Disruptions in any one segment of the supply chain network in a highly synchronized environment, will affect the whole chain. In turn, this causes a ripple effect triggering unforeseen consequences across the network.

Where problems persist, the alternative is to change the routing. From a liner perspective, this does not present too many difficulties - as it simply involves either a new string or new port calls along an existing string. However, for land based operators and particularly for inland distribution systems, new routings and new volumes are much more difficult to accommodate especially if the current network is working at capacity. Land-based movements consist of two key components: landside movements relating to getting the goods to or from the port gate and port based movements, relating to the activities within the port.

Within the port, productivity is cited as one of the key reasons for schedule variability (Panayides and Song, 2008). The continuing drive towards larger vessels on key routes, coupled with a slowing in port development, particularly in western countries will only serve to create even greater pressure on the existing port infrastructure and processes. Notteboom and Rodrigue (2008) forecasted that by 2010–2015, the performance requirements for a global hub and gateway terminals on mainline vessels would typically take the shape of:

a. A sustainable ship output of 5,000 moves per 24 h;
b. A sustainable ship-to-shore gantry crane output of 40 moves per gross hour;
c. A ratio working time to time at berth of 90%;
d. An average number of gantries operating per main-line vessel of six; and
e. An annual throughput per berth of 1.5 million TEU.

Currently a 10,000 TEU vessel with only three ports of call in Europe would imply an average number of moves of about 6,600 TEU (loading and discharging) in each port of call. When the new 18,000 TEU vessels come online this figure is likely to double. In either event such large volumes pose a significant problem for the density of container cranes per vessel, on yard equipment and on the required stacking area. The increased pressures on port infrastructure will serve to increase the levels of variability across the supply chain, so it is imperative that customers seek to utilise those ports that are best equipped to meet the demands of the carrier used as opposed to the volume that the customer is moving on the carrier.

One of the easiest ways to manage this is to seek to contract with carriers that either own the ports they are visiting or have long-term berthing contracts in place; these arrangements will help to minimize the occurrence of port related schedule variability. The expectation is that carriers providing a door-to-door service should be able to provide actual time based information relative to time taken from berthing to departing the port gate and visa-versa.

In addition to the time taken to process manufacture goods and the subsequent transportation; there is the ‘dwell’ time that can cause further variability within the supply chain. The dwell time is the time that the goods are not being improved or moving toward the final destination. This time adds no value to the goods; though it does raise the chances of further delay as it normally denotes a time when the goods are transferred from one operator or transport mode to another. Understanding the dwell time is important as it has the potential to increase costs via increased inventories, demurrage, and detention[1].

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[1] Demurrage costs relate to a full container, whilst detention costs relate to holding empty containers, normally the time between unpacking at the destination and returning them to the beneficial owner.

2.4. Frequency

Invariably, if a supplier misses a sailing because of variability in delivery times on the factory-to-port transport route a customer waiting for the goods would have to hold substantial inventory to cover these delays which may extend to weeks of extra stock. The frequency of the service influences how much impact missing a sailing has on the overall supply chain and the customer. In addition, with a weekly sailing, vehicles delivering the containers to the ship all tend to arrive a few days before sailing leading to port congestion and inefficient use of the vehicles. Maersk has recently introduced a new product called "DailyMaersk", where the shipment frequency is changed from weekly to daily sailings from key ports in Asia to Northern Europe. In section 3.3 we will simulate the effect of changing the service frequency from weekly to daily on shipper's inventory management.

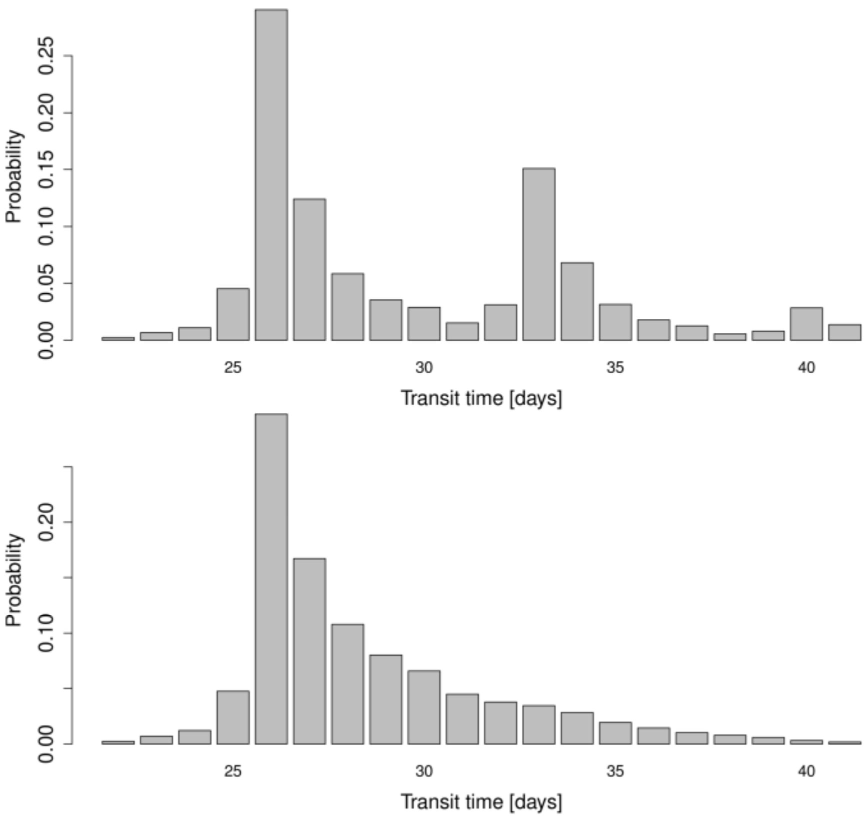

Figure 3: Transit time probability function with a weekly service (top) and daily service (below) based on Drewry (2010) delay statistic.

The effect of the shipment frequency can be seen on the distribution of transit times from factory to the destination warehouse. In both cases the port-to-port transit time distribution per vessel is as shown in Figure 3. The distribution changes when interacting effects in the supply chain view are considered. An important effect on door-to-door transit time is due to the reliability of the container transportation from the factory to the port of origin. An unreliable delivery at this stage causes the container to be rolled; the container misses the planned vessel and has to be shipped with the next vessel. The frequency of departures has an impact on the overall delay caused. The shipment frequency in the upper plot is once per week, rolling a container causes not only an increasing mean door-to-door transit time, but also increases the variability of the transit times considerably. In case of daily shipments this effect is almost gone.

3. The impact of the time factor on supply chain performance

In this section we build a stochastic, discrete event simulation model based on data and parameters gathered through interviews and industry reports such as the Drewry report. We simulate the effect of different parameters of GOTNs such as mean port-to-port transit time, the variability of port-to-port transit, mean factory-to-port transport time, the variability of the factory-to-port transport time and the service frequency on inventory related key performance indicators of the shipper. In particular, we are interested in the on-hand inventory of the shipper as this can be seen as a good proxy for required safety stocks to meet service levels, and the total inventory in the supply chain. The total inventory not only includes the on-hand inventory but also the pipeline inventory in transit. As such this is a good proxy for total inventory related cost through holding costs and interest rates.

One of the key variables affecting inventory control policy and resulting costs is the replenishment lead time. Inventory position should be set such that the total inventory in transit (pipeline inventory) and at the stocking point (on-hand inventory) can cover the demand during lead time. When lead time demand is uncertain, on-hand inventory includes some safety stock in order to hedge against the deviations in lead time demand in addition to the cycle stock. Key components of lead time where uncertainty exists are the uncertainty in production process and the transportation time from the supplier to the stocking point. Since our aim is to analyze the time factor in ocean shipping we will ignore the production time and in the following discussions we use transit time as the total lead time.

The three aspects of time factor affect the three components of total inventory in the following ways. Pipeline inventory increases with (mean) transit time and is independent of transit time variability. Cycle stock is a function of the replenishment frequency which in our context has a direct relation to shipment frequency. Cycle stock decreases when replenishment can be made more frequently. Safety stock is a function of mean transit time and transit time variability. The impact of mean transit time on safety stock is only through the variance of demand. If demand is not probabilistic, safety stock is affected only by lead time variance and not the mean.

These relations are relevant when inventory position is determined based on a given service level. If the inventory level is kept constant a change in transit time would result in a change in service level. Service level decreases when mean and/or variance of transit time increases or when the frequency decreases.

Here, we discuss the impact of the three transit time components on inventory and service levels. We present fill rate as the service level measure. Fill rate is the percentage of demand which is satisfied immediately from stock on hand. A base stock policy is assumed for inventory control purposes: in every replenishment period inventory position (IP) is observed and enough is ordered to raise IP to the predefined base stock level (S). The replenishment period depends on the frequency of shipments i.e. if a shipment is possible each T days then replenishment period is every T days. For example, if a ship departs once a week, an order can be placed once a week. Unsatisfied demand during a period is assumed to be backordered.

Impact of lead times on inventory and service levels has been studied extensively. One stream of research is on the optimal inventory control policies with random lead times. When lead times are random, it is difficult to develop optimal policies precisely and therefore using a normal approximation for lead time demand is the traditional approach. However several studies (e.g. Eppen and Martin, 1988; Robinson et al, 2001; Chopra et al, 2004) show that the error resulting from this approximation can be significantly large. On the other hand, correct optimal policy is difficult to characterize and the computational requirements can be very large (Srinivasan et al 2011). Additionally, it is often not possible to compute optimal inventory policy for a fill rate target. For these reasons, in the following, we report inventory and service levels generated from a simulation study.

There exist several studies about the impact of lead time improvement on supply chain performance. Many of these studies consider improvements in production lead times and/or they treat lead time as an aggregate time including production and delivery times (see for example De Treville et al 2004 and the references therein). Tyworth and Zeng (1998) is one of the few papers studying explicitly the effect of carrier transit time performance on logistics cost and service levels. They model lead time as the sum of a random transit time and a constant processing time.

In our study, we model D2D transit times in three parts: landside activities at the origin including the landside movements and port handling at the origin (we call this factory-to port time); P2P times (ocean transit times); and landside activities at the destination, which is assumed to be fixed without any variability. Hence, our focus is on the variability and possible delays before and during the ocean transportation. To our knowledge, the only study with such a decomposed approach is by Leachman (2008) where he models the impact of transit time improvements after the ocean transportation, from the destination port to the trans-load warehouses.

Our simulation is based on data from a variety of sources. These include industry reports (for example, Drewry) and data collected through interviews with various companies operating in logistics.

The random variable F2P consists of a deterministic part (D1) and a random part (R1) which is distributed according to an exponential distribution, F2P=D1+R1. Similarly, port-to-port transit time, P2P=D2+R2 where R2 is distributed according to the empirical delay distribution in Table 1. Depending on the frequency of shipments, total transit time distribution is unimodal or multimodal as illustrated in Figure 3.

For better clarity and simplicity we show the impact of the ocean transportation and landside activities on the overall inventory performance based on a single product. The demand follows a normal distribution with a coefficient of variation of 0.1. All inventory-related performance measures are reported in days of demand. That way we only report relative figures.

3.1. Mean transit time

The following simulation study analyses the impact of the mean port-to-port (P2P) transit time on the shipper's inventory management. Values are chosen such that they reflect typical transit times on the Asia – Northern Europe route. Motivated by the Drewry schedule reliability statistics, on top of the promised/average transit time we add a mean delay of one day with a standard deviation of 2.05 days as illustrated in Table 1. If not otherwise specified, we use a factory-to-port (F2P) time with a mean of 6 days and a standard deviation of 4 days.

Table 2: On-hand inventory in days of demand with different promised port-to-port transit times for daily and weekly sailings.

	Daily sailings				Weekly sailings			
	Fill rate				Fill rate			
P2P mean	96.0%	98.0%	99.0%	99.5%	96.0%	98.0%	99.0%	99.5%
25	2.7	3.1	3.3	4.0	7.6	9.1	10.7	12.3
27	2.8	3.2	3.4	3.8	7.6	8.9	10.9	12.3
29	2.9	3.4	3.6	3.7	7.4	9.2	10.9	12.1
31	2.9	3.5	3.9	4.0	7.4	9.2	10.7	12.3
33	2.5	3.6	4.1	4.4	7.7	9.1	10.9	12.3

Table 3: Total inventory in days of demand with different promised port-to-port transit times for daily and weekly sailings.

	Daily sailings				Weekly sailings			
	Fill rate				Fill rate			
P2P mean	96.0%	98.0%	99.0%	99.5%	96.0%	98.0%	99.0%	99.5%
25	41.1	41.5	41.7	42.4	47.3	48.7	50.4	52.0
27	43.2	43.6	43.8	44.1	49.3	50.6	52.6	54.0
29	45.3	45.7	46.0	46.1	51.1	52.9	54.6	55.8
31	47.3	47.9	48.2	48.4	53.1	54.9	56.4	58.0
33	48.9	50.0	50.5	50.8	55.4	56.8	58.6	60.0

Tables 2 and 3 show the mean effect of P2P transit time on the on-hand inventory (OHI) and the total inventory in days of demand. For any level of fill rate, both OHI and total inventory increases as mean P2P time increases. The same can be observed for a change in mean F2P time (see Tables 4 and 5) with nearly the same margins. A change in mean time at the landside movements at the origin or at the ocean transit has nearly the same effect on overall inventory performance.

Table 4: On-hand inventory in days of demand with different factory-to-port mean transit times for daily and weekly sailings.

	Daily sailings				Weekly sailings			
	Fillrate				Fillrate			
F2P mean	96.0%	98.0%	99.0%	99.5%	96.0%	98.0%	99.0%	99.5%
4	2.3	3.0	3.3	3.5	7.4	9.0	10.8	12.0
6	2.5	2.9	3.1	4.0	7.5	9.1	10.8	12.1
8	2.5	2.7	3.5	4.1	7.5	9.1	10.7	12.1
10	2.4	2.9	3.7	4.1	7.5	9.0	10.7	12.2

Table 5: Total inventory in days of demand with different factory-to-port mean transit times for daily and weekly sailings

	Daily sailings				Weekly sailings			
	Fillrate				Fillrate			
F2P mean	96.0%	98.0%	99.0%	99.5%	96.0%	98.0%	99.0%	99.5%
4	29.7	30.4	30.7	30.9	36.1	37.7	39.5	40.7
6	31.9	32.3	32.5	33.4	38.2	39.8	41.5	42.8
8	33.8	34.1	34.9	35.5	40.2	41.8	43.4	44.8
10	35.8	36.3	37.1	37.5	42.2	43.7	45.3	46.9

3.2. Variability

Tables 6 and 7 depict the inventory levels for changing standard deviation (SD) of ocean transit time (P2P SD) and landside activities (F2P SD). When shipments are daily the improvement in the variability of factory-to port and port-to-port times have similar impacts on the inventory level. On the other hand, for weekly shipments improvement in the variability of F2P time seems to have a higher impact than an improvement in variability of P2P time. For example, when both standard deviations are 2, a fill rate of 98% can be reached by an OHI of 8.0. A reduction in the SD of F2P to zero reduces the OHI to 6.5 while the same reduction in SD of P2P to zero has almost no effect (8.0 to 7.6). This can be explained by the combined effect of probability and impact of missing the sailing. With weekly shipments, the impact of missing a ship is relatively large. Therefore, reducing the probability of missing the ship has a high impact on the performance. On the other hand, with daily shipments, the system is more robust to the reliability of F2P transport.

Table 6: On-hand inventory in days of demand with different standard deviations of port-to-port and factory-to-port transit times for daily and weekly sailings.

		Daily sailings				Weekly sailings			
		Fill rate				Fill rate			
P2P stddev	F2P stddev	96.0%	98.0%	99.0%	99.5%	96.0%	98.0%	99.0%	99.5%
2	4	2.5	2.9	3.1	4.0	7.4	9.1	10.8	12.1
0	4	2.1	2.4	2.9	3.5	7.0	8.6	10.6	12.5
2	2	2.0	2.4	3.1	3.5	6.7	8.0	8.6	10.2
0	2	1.5	1.8	2.5	2.9	7.1	7.6	8.6	9.2
2	0	1.9	2.5	2.7	2.9	5.1	6.5	7.8	8.5
0	0	0.9	0.9	0.9	1.5	3.4	3.8	4.0	4.1

Table 7: Total inventory in days of demand with different standard deviations of port-to-port and factory-to-port transit times for daily and weekly sailings

		Daily sailings				Weekly sailings			
		Fillrate				Fillrate			
P2P stddev	F2P stddev	96.0%	98.0%	99.0%	99.5%	96.0%	98.0%	99.0%	99.5%
2	4	31.9	32.3	32.5	33.3	38.1	39.8	41.5	42.8
0	4	30.5	30.8	31.3	31.9	36.7	38.3	40.3	42.2
2	2	30.7	31.1	31.8	32.2	36.8	38.1	38.7	40.3
0	2	29.3	29.5	30.2	30.6	36.2	36.7	37.7	38.3
2	0	29.9	30.5	30.7	30.9	33.1	34.5	35.8	36.5
0	0	27.8	27.9	27.9	28.5	30.4	30.8	31.0	31.1

The impact of the shipment frequency can be observed in Tables 2 to 7. For any desired level of fill rate, OHI increases by 3-7 days of demand when shipment frequency decreases from daily shipments to weekly shipments, while total inventory increases by up to 7 days of demand.

Additionally, as discussed in the previous section, increased frequency results in a more robust system with respect to delays in the landside activities at the origin.

3.3. Integration of supply chain activities and ocean transport

Recently there have been attempts from major shipping companies to both improve the schedule reliability and at the same time to increase the frequency of shipments. An example is Maersk, who have introduced "Daily Maersk", a shipment product combining both high schedule reliability with high shipment frequency. The aim is to provide a constant, predictable shipment time from the announced cut-off time to the availability of the container to the shipper at the port of destination.

In this respect, we analyze the effect of such a combined time factor improvement on the inventory performance. We compare current shipments running weekly and daily with a daily, reliable shipment. In order to achieve this reliability, the third option announces an about 10% longer port-to-port transit time. As can be seen from the inventory performance, this increase in mean port-to-port transit time is overcompensated by the effect of the reduction in variability and reliability. Inventory reduction potentials when high service levels are required can be around 10 days on safety buffers (on-hand inventory) and up to 17 days on total inventory, where the major improvement comes from the change in frequency.

Table 8: On-hand inventory in days of demand for weekly shipments with delays, daily shipments with delays, and daily, reliable shipments.

		Fillrate			
		96.0%	98.0%	99.0%	99.5%
Weekly	current	8.5	10.5	12.0	13.0
Daily	current	2.5	3.4	3.8	4.1
Daily	reliable	1.9	2.4	2.7	2.8

Table 9: Inventory position in days of demand for weekly shipments with delays, daily shipments with delays, and daily, reliable shipments.

		Fillrate			
		96.0%	98.0%	99.0%	99.5%
Weekly	current	43.8	45.8	47.3	48.3
Daily	current	32.5	33.4	33.9	34.1
Daily	reliable	29.9	30.5	30.8	30.9

4. Conclusion

Improvements in mean transit time have the expected impact on key inventory performance indicators. There is no significant difference if the improvement comes from different stages in the D2D transportation chain. It should be noticed that in this study we report finings based on the assumption that the replenishment system is aligned with the schedules of the transportation system. If this is not the case, the benefit of increasing the frequency of shipments will be even higher, since the mean waiting time for the next shipment will decrease.

Improvements in variability have different impacts, depending on the source of the variability and the frequency of the shipments. The highest inventory reduction potential arises from a combination of high reliability and improved frequency.

The move towards a service-orientated approach by some of the operators in the market place provides an opportunity for customers to ask for more performance related data at both the tendering and operational stages of the contract process. The companies we spoke with echoed this, though with the caveat that customers need to understand what the data reflects and how it was gathered. Furthermore, companies felt that there should be a mutual understanding as to how the data would be manipulated or presented. The prime example in this instance is transit time. Carriers are very conscious that transit time reflects a port-to-port movement, whereas customers are looking for a breakdown of the door-to-door movement

As identified in our variability section above, land-based sections of overall D2D movements are often the most variable, so it is important to establish how these performance will be measured and by whom. The interviews indicated that many of the shipping company's sub-contract land based movements out to third parties, so they in turn are reliant on another transport company. Maersk made specific comment on removal of service offerings because they could not guarantee reliability of the land-based movements.

There are two distinct phases that reflect the need for greater review, the RFI process and the on-going contract management process. In both instances, there should be a focus on the areas causing the greatest degree of variation across the supply chain.

Core measurements should focus on overall D2D transit times, segmented down to the lowest common portion. The D2D transit consists of a number of handoffs, and the difficulty lies in obtaining an accurate measurement of the time spent in each segment and then breaking that down into the time that is actually adding value and the dwell time. Even across the simplified process, the five stages have a minimum of seven modal handoffs, each driving two key measurements – value add and dwell.

Due to a lack of data we were not able to model the variability of the hinterland transport after the port of arrival. However, as variability of the domestic hinterland transport has no further impact on the ocean transport system (unlike the variability of the transport from the factory to the port of departure where the risk is to miss a sailing), this effect can be analysed independently.

This work can be extended in many ways. Based on the work of Ducruet and Van der Horst (2009), it would be very interesting to analyse how integration of the hinterland transport system with the GOTN and the port would impact the shipper through different levels of variability. An interesting and relevant extension could also be to consider the environmental impact of the performance of GOTNs through the shipper's inventory management. In particular, if shippers have high service level requirements then the need for emergency shippings by air freight in case of an unreliable ocean transport system could increase. This not only will affect the shipper's cost but the environmental impact as well.

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